GEODETIC CONTROL MANUAL

CITY OF CINCINNATI

DEPARTMENT OF PUBLIC WORKS

INTRODUCTION

RIVERFRONT STADIUM

INTRODUCTION

GENERAL

This manual is published by the City of Cincinnati, Department of Public Works, Division of Engineering. It is prepared to allow convenient access to geodetic control information within the City of Cincinnati by surveying and engineering professionals.

The manual is divided into several sections. The **INTRODUCTION** section gives background information and guidance in the use of the City's geodetic control network.

The next four sections provide the latest geodetic control information for monuments recently placed within the City. As in previous manuals, they have been divided into four quadrants: **NORTHEAST, NORTHWEST, SOUTHEAST,** and **SOUTHWEST.** Index maps are provided at the beginning of each section to allow quick access to monuments close to areas of interest. The monuments are arranged in ascending numerical order within each section.

TABLE A lists these monuments, with their respective coordinates and elevations, in numerically ascending order. **TABLE B** lists monuments remaining from previous manuals along with respective coordinates and elevations (based upon NAD 27 and NAVD 29). **TABLE C** provides descriptions and locations of towers and other reference stations, the 9000 series, located throughout the area that are useful for obtaining grid bearing references.

Monuments established for the purpose of this program range in number from 6900 through 7100. They have generally been placed in pairs to facilitate azimuth determination. Except where otherwise noted, the control network contained herein is based upon NAD 83 and NAVD 29. Horizontal and vertical control information for monuments remaining within the City of Cincinnati described in previous manuals are given in TABLE B; however, specific descriptions of these monuments and azimuth values are not contained herein. For more information on these monuments, please contact the Supervising Surveyor on (513) 352-3425.

The user of this information should be familiar with the differences between NAD 27 and NAD 83. Software exists to translate values between these two horizontal data (for example, NADCON, CORPSCON, and so on). However, this software is limited in accuracy of translated values.

While this manual provides excellent coverage for much of the City, more work is ongoing. In addition, the NGS is currently readjusting the vertical control network. This readjusted network, identified as NAVD 88, will replace the previous vertical datum, NAVD 29. Values for NAVD 29 and NAVD 88 will be included in future updates of this manual. Updates will generally be mailed on an annual basis to all parties registered with the Division of Engineering (see the ***Registration Form*** at the end of the Introduction Section).

Much time and effort has been spent in obtaining the information contained in this manual and ensuring its accuracy. However, it is realized that errors and inconsistencies may be present in this manual. Please bring any such errors and omissions to the attention of the Principal General Design Engineer (address: City Hall, Room 445, 801 Plum Street, Cincinnati, Ohio 45202-1980; Telephone: (513) 352-3425; FAX: (513) 352-1581). Your cooperation is truly appreciated.

HISTORICAL

Establishment of surveying control networks within the City of Cincinnati has been an evolutionary process beginning well before the turn of the century. Useful for relating public improvements, mapping, and other geographic referencing needs, the networks have been used for a variety of local purposes, ranging from providing elevations necessary for sewer improvements, to furnishing a reference system for airports, to establishing the horizontal and vertical control system for the Cincinnati Area Geographic Information System (CAGIS).

By law, early surveys referenced a horizontal mark on a plate at the Hamilton County Court House for vertical control (see ***Datum*** portion of this Section). While this system standardized the vertical referencing system within the City, it had several drawbacks.

- This datum did not directly relate to other areas. Surrounding cities, townships, and states used different systems. Therefore, any projects involving other jurisdictions required continual adjustments and were subject to serious errors due to these differences.

- This system was inconvenient to use. To bring the datum to a project, level circuits had to be run from the County Court House to the project site. This process delayed and increased the cost of obtaining field information and substantially increased the probability of error.

In the early part of this century, the City undertook a program to solve these problems. In October 1913, *PERMANENT BENCH MARKS* was published. Established by the Topographic Survey of 1912, this book documented the descriptions and elevations of 217 monuments located throughout the City. These bench marks were placed in pairs about a block apart, the distance between pairs being about one mile. As stated in this manual "*By this arrangement, a convenient means is available for checking level work, as it will never be necessary to depend upon the elevation of a single bench mark.*" Vertical control for these monuments were referenced to elevations established by the Coast and Geodetic Survey (C&GS). For the first time, the vertical datum referenced mean sea level.

This network was extended through 1933 and was supplemented with additional bench marks in the vicinity of Blue Ash Airport in 1945. When completed, this early system had bench marks with numbers between 1 and 450.

While this system resolved many of the early problems associated with local control networks, it remained primarily a vertical referencing system (used to determine elevations). No horizontal information was available for locating improvements with respect to others.

The United States Coast and Geodetic Survey (USC&GS), successors of the C&GS, established a local first order horizontal and vertical control network in 1947 for a joint city-county survey. Based upon this control network, additional monuments were placed throughout Hamilton County in an attempt to allow better public access to vertical and horizontal control information. Additional 1000 and 2000 series monuments were added to this network, with the 1000 series monuments generally located west of the Vine

Street-Springfield Pike line. The 2000 series is generally located east of that line. To make this information more accessible to surveyors and engineers, the *BENCH MARK MANUALS OF 1954* and *1963* were published.

During the ensuing decades, as with many other components of the City's infrastructure, the bench mark system gradually deteriorated. Public and private improvements destroyed many of these monuments. When last surveyed in 1989, only 236 of 530 bench marks included in the *BENCH MARK MANUAL OF 1963* still existed within the City of Cincinnati.

Other changes also occurred in this period. The National Geodetic Survey (NGS) replaced the USC&GS as the federal curators of horizontal and vertical control networks. Beginning in 1975 and finishing in 1986, NGS readjusted and redefined the previous horizontal datum, NAD 27. This new horizontal datum, NAD 83, was established to improve the quality of control required by engineers and surveyors without regional recomputations to repair the existing network. Modern technology was developed that provided quicker and more accurate horizontal locations through the use of the Global Positioning System (GPS), a system using satellites and receivers to determine ground positions.

In December 1987, the *INFRASTRUCTURE COMMISSION REPORT* was submitted to City Council. Based upon recommendations contained in that report, the City began funding a program in 1989 to improve its geodetic control system. The goal of this program is to make horizontal and vertical control of high quality accessible to surveyors, engineers, mapping professionals, developers, and any others that may require locations referenced to a regional or national network. While this control network is not complete, our goal is to provide sufficient control so that most areas of the City are within one-half mile of a control monument. Generally located in parks, recreational areas, and school properties, these monuments will be both accessible to the public and more sheltered from destruction due to future public or private improvements. This manual is the result of that effort.

DATUM INFORMATION

All references herein to NAD 83 shall mean the Ohio coordinate system of 1983, south zone. This datum is a Lambert conformal conic projection of the North American datum of 1983, having standard parallels at north latitude 38° 44′ and 40° 02′, along which parallels the scale shall be exact. The origin of coordinates is at the intersection of the meridian 82° 30′ west of Greenwich and the parallel 38° 00′ north latitude. This origin is given the coordinates x = 600,000 meters and y = 0 meters.

All references herein to NAD 27 shall mean the Ohio coordinate system of 1927, south zone. This datum is a Lambert conformal conic projection of the Clarke spheroid of 1866, having standard parallels at north latitude 38° 44′ and 40° 02′, along which parallels the scale shall be exact. The origin of coordinates is at the intersection of the meridian 82° 30′ west of Greenwich and the parallel 38° 00′ north latitude. This origin is given the coordinates x = 2,000,000 feet and y = 0 feet.

All references to NAVD 29 shall mean the North American Vertical Datum of 1929; references to NAVD 88 shall mean the North American Vertical Datum of 1988.

Except as specifically described in this manual, references to feet shall mean U.S. Survey feet. Conversion between the metric system and U.S. Survey feet is given by the following relationship:

1 meter = (3937/1200) U.S. Survey feet

Horizontal Datum

Horizontal positions, state plane coordinates or geodetic positions, contained in this manual reference NAD 83, unless otherwise indicated. The standard of length for this datum is the meter.

Horizontal positions for existing monuments contained in TABLE B reference NAD 27. The standard of length for this datum is the U.S. Survey foot.

The user should note that there are significant differences between the two datums, with no linear translation between them.

Vertical Datum

Vertical positions (elevations) currently reference NAVD 29.

Prior to 1912, elevations within the city referenced a horizontal mark on a plate at the Hamilton County Court House. The zero or datum of this old official benchmark was 120.62 feet below it, or at an elevation of 431.29 NAVD 29. In order to equate older elevations to NAVD 29, add 431.29 to elevations referencing the metal plate.

The NGS is currently readjusting the national network under NAVD 88. These values will be included in future updates to this manual.

Azimuths

Azimuths contained in this manual are *grid* bearings and not *geodetic* bearings. Accuracy of these bearings is ± 10 seconds. The convergence, or mapping, angle has been included for conversion from the grid bearing to the geodetic bearing.

RECOVERY INFORMATION

Please contact the Supervising Surveyor (513) 352-3425 if damage is noted to these or any other surveying monuments located within the City of Cincinnati. Please provide the monument location and number.

REGISTRATION

Owners of this manual should fill out and return the Registration Form contained in this manual. Updates will be mailed only to those registered in this manner.

ADDITIONAL COPIES

Additional copies of this manual are available from Engineering / Technical Support, City Hall, Room 420. A fee will be charged to cover the cost of reproduction.

ACKNOWLEDGEMENTS

Publication of this manual is the result of the hard work and efforts of many groups and individuals. Members of the Infrastructure Commission, City Administration, City Council, and the citizens of Cincinnati were critical to the initiation of this effort. In addition, the Cincinnati Recreation Commission, the Park Department, and the Cincinnati School Board have been extremely cooperative and are thanked for their efforts. Michael J. Stanoikovich and Thomas F. Mochty of Woolpert Consultants, who provided the control work contained in this manual and created this manual, deserve sincere thanks for their diligent efforts. Mr. David Conner of the National Geodetic Survey has provided great assistance and sincere interest in ensuring the quality of the information provided. And finally, sincere thanks to Mr. Joseph N. Koopman, P.S. His foresight, dedication, and diligence are key reasons for successfully changing the City's control network from disrepair to a model for others to follow.

Example Survey Using State Plane Coordinates

PROBLEM

A second order traverse was run from City of Cincinnati GPS control station 6903 and closed at another City of Cincinnati control station 7028. Three intermediate traverse stations T-1, T-2, T-3 were established. At Station T-2 side shots were taken to the four corners of Lot A. Given the control information data and the reduced field note information of the traverse, compute the adjusted NAD 83 state plane coordinates (Ohio South Zone 3402) of the intermediate traverse stations and property corners of Lot A. The reduced field notes use the following assumptions:

- Traverse was oriented with respect to grid azimuth at the starting control station.
- Observed directions have been adjusted for closure.

Control information data:

GPS Control Station 6903

N_1 = 419,784.372 (Northing in U.S. Survey Feet)
E_1 = 1,369,818.747 (Eastings in U.S. Survey Feet)
H_1 = 885.630 (Elevation in U.S. Survey Feet)
K_1 = 0.99994545 (Grid Scale Factor)
G_1 = -112.861 (Geoidal height in U.S. Survey Feet)
Grid Azimuth to Station 6904 = 35° 55′ 03″

GPS Control Station 7028

N_2 = 419,920.703
E_2 = 1,371,512.837
H_2 = 878.97
K_2 = 0.99994542
G_2 = -112.861
Grid Azimuth to Station 7019 = 92° 07′ 43′

Station		Grid Azimuth	Ground Distance Horizontal (U.S. Feet)	Elevation (U.S. Feet)
Occ.	Obs.			
6903				885.630
	6904	35-55-03		
	T-1	106-56-13	461.302	770.520
T-1				
	T-2	63-26-05	447.254	690.100
T-2				
	Cor-1	225-00-00	70.717	710.100
	Cor-2	75-57-49	206.173	730.000
	Cor-3	111-48-06	269.281	685.000
	Cor-4	146-18-36	180.294	700.500
	T-3	53-07-48	500.045	820.750
T-3				
	7028	116-51-21	507.629	878.970
7028				
	7019	92-07-43		

SOLUTION

Steps:

1. Draw a sketch.

2. Analyze the grid scale factor for the project. A mean of the published point grid scale factors of the control points may be adequate for all lines in the project.

   The Ohio South Zone uses the Lambert Projection and for the Lambert grid coordinates, the formula for computing the grid scale factor, K at any given point is,

$$K = \frac{(1-e^2 \sin^2 \emptyset)^{1/2} R \sin \emptyset_0}{a \cos \emptyset}$$

Where e^2 = eccentricity squared of the GPS 80 ellipsoid
= 0.0066943800229034
R = mapping radius at latitude 0
0_0 = latitude, the true projection origin = 39.38435851118
a = semi major axis of the GRS 80 ellipsoid = 6,378,137m
= 20,925,604.47 U.S. feet

For second order traverse, it may be sufficient to calculate the average $\overline{K}$.

$$\overline{K} = \frac{\sum_{i=1}^{n} K_i}{n}$$

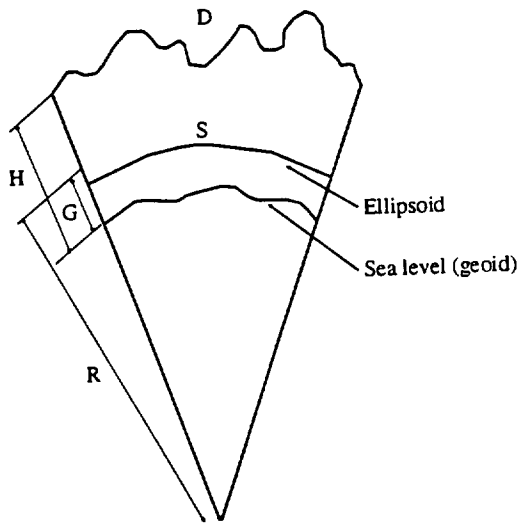
Where n = No. of control points.

For surveys requiring better accuracy, a more accurate formula for $\overline{K}$ may be used, (refer to NOAA Manual Nos. NGS 5, State Plane Coordinate System, 1983, pp 49-50)

$$\overline{K} = \frac{K_1 + 4K_m + K_2}{6}$$

Where K_m = grid scale factor at the midpoint of the line joining points 1 and 2.

3. Analyze the elevation factors for the project. Observed horizontal distance must be reduced to reference ellipsoid by applying this factor, as shown in the sketch.



By proportion,

$$\frac{S}{D} = \frac{R}{R+H+G} = C_H$$

Where C_H = elevation factor
S = ellipsoidal distance
D = horizontal distance
R = mean radius of the earth = 6,372,000m = 20,906,000 feet
H = mean elevation
G = geoid-ellipsoid separation (geoidal height)
+G if ellipsoid is below the geoid
-G if ellipsoid is above the geoid

Note, that in the conterminous U.S. the GRS 80 (WGS84) ellipsoid is always above the geoid as shown in the figure.

4. Compute the combined factor, $C = \overline{K}.C_H$ for each observed horizontal distance.

5. Reduce the horizontal distance to the grid by multiplying the observed horizontal distance by its corresponding combined factor.

6. Adjust the traverse using the compass rule adjustment method.

7. Compute the adjusted NAD 83 State Plane Coordinate of each point.

Step 1

See sketch.

Step 2

Compute grid scale factor $\overline{K}$

$$\overline{K} = \frac{1}{2}(K_1 + K_2)$$

$$= \frac{1}{2}(0.99994545 + 0.99994542)$$

$$= 0.999945435$$

Step 3

Compute elevation factor for each line.

$$C_H = \frac{R}{R + H + G}$$

Where R = 20,906,000 feet
G = mean geoidal height
= ½ (G_1 + G_2) = ½ [(-112.861) + (-112.861)]
= - 112.861 feet

In the Cincinnati area G averaged about -112.5 feet. Say we compute C_H of line 6903 to T-1, call it C_{H1}

H_1 = Mean elevation of 6903 and T_1
= ½ (885.630 + 770.520) = 828.075 feet

C_{H1} = 20,906,000/(20,906,000 + 828.075 -112.861) = 0.999965790

Step 4

Compute the combined factor $C = \overline{K}.C_H$, say for line 6903 to T-1, call it C_1

$C_1 = \overline{K}.C_{H1} = 0.999945435\ (0.999965790)$
$= 0.999911227$

Step 5

Compute the grid distance by multiplying measured horizontal distance by combined factor, say for line 6903 to T-1, the grid distance is 461.302 (0.000011227) = 461.261 feet.

Steps 3 to 5 may now be summarized in tabulated form as follows:

Line	K	C_H	C	Grid Distance
6903-T1	0.999945435	0.999965790	0.999911227	461.261
T1-T2	0.999945435	0.999970466	0.999915903	447.216
T2-Cor1	0.999945435	0.999971911	0.999917348	70.711
T2-Cor2	0.999945435	0.999971435	0.999916872	206.156
T2-Cor3	0.999945435	0.999972512	0.999917948	269.259
T2-Cor4	0.999945435	0.999972141	0.999917577	180.279
T2-T3	0.999945435	0.999969265	0.999914702	500.002
T3-7028	0.999945435	0.999964748	0.999910185	507.583

Step 6

Adjust the traverse,

Station	Grid Az.	Grid Dist.	Latitude	Departure	Grid Coordinates	
					Northings	Eastings
6903				FIXED	419,784.372	1,369,818.747
	106-56-13	461.261	-134.374	+441.254		
T-1					419,649.998	1,370,260.001
	63-26-05	447.216	+200.003	+400.001		
T-2					419,850.001	1,370,660.002
	53-07-48	500.002	+300.002	+400.001		
T-3					420,150.003	1,371,060.003
	116-51-21	507.583	-229.299	+452.838		
7028					419,924.704	1,371,512.841
				FIXED	419,920.703	1,371,512.837

$$\Sigma\, Lat = +136.332$$
$$N_{7028} - N_{6903} = +136.331$$
$$dN_t = -0.001$$

$$\Sigma\, Dep = +1694.094$$
$$E_{7028} - E_{6903} = +1694.090$$
$$dE_t = -0.004$$

$$L = \Sigma\, Grid\ Dist. = 1916.062$$

$$Closure\ correction,\ d_c = \sqrt{dN_t^2 + dE_t^2}$$

$$= \sqrt{(-0.001)^2 + (-0.004)^2}$$

$$= 0.004\ feet$$

Compute corrections ΔN_i and ΔE_i to N, and E, respectively using compass rule.

ΔN_i = correction to N_i
ΔE_i = correction to E_i
dE_T = total closure connection of the traverse in the N coordinate
dN_T = total closure correction to the traverse in the E coordinate
L_i = distance from station $_i$ to the initial station
L = total length of traverse

$\Delta N_i = L_i \ \Delta N_T/L$ and $\Delta E_i = L_i \ dE_T/L$

$\Delta N_i = (461.261)\ (-0.001)/1916.062 = 0.000$

$\Delta N_2 = (908.477)\ (-0.001)/1916.062 = 0.000$

$\Delta N_3 = (1408.479)\ (-0.001)/1916.062 = -0.001$

$\Delta E_1 = (461.261)\ (-0.004)/1916.062 = -0.001$

$\Delta E_2 = (908.477)\ (-0.004)/1916.062 = -0.002$

$\Delta E_3 = (1408.479)\ (-0.004)/1916.062 = -0.003$

Step 7

Compute the adjusted grid coordinate N_{ci}, E_{ci} of the traverse stations and lot corners.

$$N_{ci} = N_{ui} + \Delta N_i$$

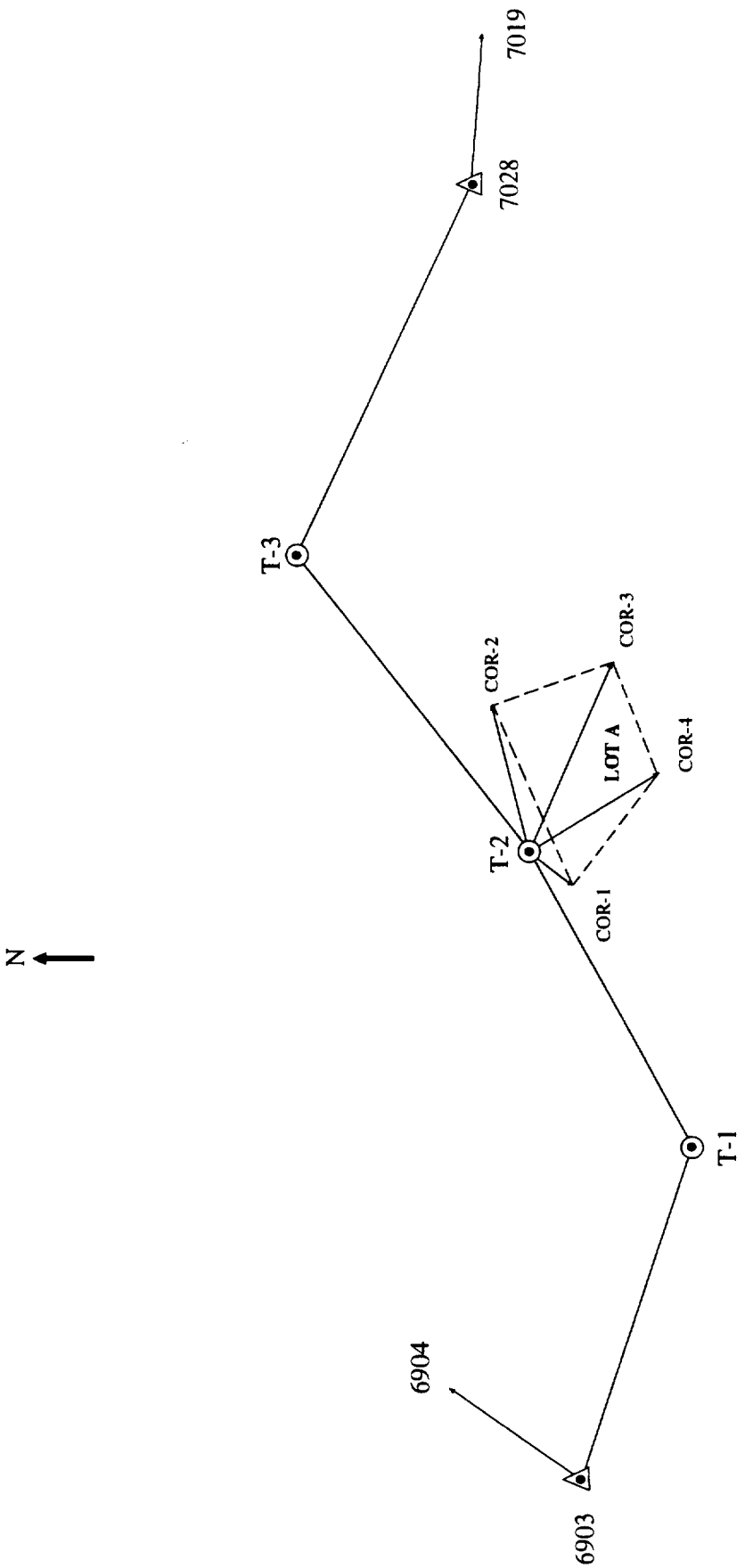
$$E_{ci} = E_{ui} + \Delta E_i$$

Where
N_{ui} = unadjusted northing of point $_i$
E_{ui} = unadjusted easting of point $_i$

Station	Unadjusted Grid Coordinate		Corrections		Adjusted Grid Coordinates	
	N_u	E_u	ΔN	ΔE	N_c	E_c
T1	419,649.998	1,370,260.001	0.000	-0.001	419,649.998	1,370,260.000
T2	419,850.001	1,370,660.002	0.000	-0.002	419,850.001	1,370,660.000
T3	420,150.003	1,371,060.003	-0.001	-0.003	420,150.002	1,371,060.000

Compute grid coordinates of corners of Lot A.

Station		Grid Azimuth	Grid Dist.	Latitude	Departure	Adjusted Grid Coord.	
Occ	Obs					N	E
T-2						419,850.001	1,373,660.000
	Cor-1	225-00-00	70.711	-50.000	-50.000	419,800.001	1,370,410.000
	Cor-2	75-57-49	206.156	50.001	200.001	414,900.002	1,370,860.001
	Cor-3	111-48-06	269.259	-100.001	250.000	419,750.000	1,370,910.000
	Cor-4	146-18-36	180.279	-150.001	100.001	419,700.000	1,370,760.001


7019
7028
T-3
COR-2
COR-3
LOT A
COR-4
T-2
COR-1
N
T-1
6904
6903

REGISTRATION FORM
(11/92)

Date: _____

Name: _____

Firm: _____

Address: _____

_____

_____

Telephone: (____) _____

FAX: (____) _____

Return to: Supervising Surveyor
City of Cincinnati
City Hall, Room 445
801 Plum Street
Cincinnati, Ohio 45202-1980